

Suppression of *Bemisia tabaci* (Homoptera: Aleyrodidae) infestations in cantaloupe and cotton with sprinkler irrigation

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A series of field experiments were conducted to evaluate *Bemisia tabaci* (Genn.) infestations in both sprinkler and furrow irrigated cantaloupe and cotton plots under conditions of intense whitefly pressure in Imperial Valley, CA. Various fungal pathogen and insecticide treatments also were compared within each irrigation regime. A consistent finding throughout all experiments was that densities of immature whiteflies were significantly reduced in sprinkler irrigated plots. This was most evident in sprinkler irrigated cantaloupe plots treated with the insecticide imidacloprid, as plants survived whitefly infestations to produce marketable fruit in these plots only. Similarly, whitefly densities in imidacloprid-treated/sprinkler-irrigated cotton were significantly lower than all other treatments. Spray applications of insect fungal pathogens were for the most part indistinguishable from the untreated control in terms of densities of whiteflies. Results from the first cantaloupe trial indicate that sprinkler irrigation on a daily schedule resulted in consistently lower whitefly infestations compared to a biweekly schedule. Published by Elsevier Science Ltd

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Outbreaks of whitefly populations in agricultural areas of the southwestern United States and northern Mexico have been particularly severe in recent years. These outbreaks coincide with the establishment of the B biotype (Costa and Brown, 1991) of *Bemisia tabaci* (Genn.) (also referred to as *B. argentifolii* Bellows & Perring), a highly polyphagous form that colonizes many vegetable and field crops grown in California, Arizona and Mexico (Brown, 1994; Perring *et al.*, 1991). Widespread damage in the irrigated desert valleys of these states has resulted when population buildup on a succession of crops culminated in outbreaks of marauding whiteflies that overwhelmed crops and pest control efforts.

Management practices in California's Imperial Valley and other outbreak regions have relied principally upon insecticides to combat whiteflies. In the absence of a comprehensive whitefly management program, few alternatives have been available. Development of integrated practices is essential to a long term strategy designed to maintain moderate and manageable levels of whiteflies. Additional effective approaches that can be incorporated into a whitefly management program are needed to attain sustainable control by lessening dependency on insecticides.

One approach that may act to depress whitefly

populations is the use of sprinkler irrigation on crops that are most susceptible to whitefly attack. The action of overhead sprinklers may simulate rainfall on a crop, which is widely believed to reduce the numbers of whiteflies. Evidence for the negative impact of rainfall on whiteflies is largely anecdotal, but accounts of brief episodes of intensive downpours that knock-down infestations, as well as extended periods of rainfall that have been linked to seasonally lower regional populations have been reported (Gameel, 1977; Zalom, Natwick and Toscano, 1985; Hilje, 1994). For example, cotton fields grown in desert regions of Arizona and southern California occasionally receive heavy summer showers that appear to immediately reduce the number of adult whiteflies (Henneberry *et al.*, 1995). The appearance may be more dramatic than the actual effect, as sessile whitefly stages are probably little impacted and adults soon rebound. Continuous bouts of rainfall, however, may eventually curb population growth rates through interference and/or mortality effects on both adults and immatures. Observations of the rise and fall of whitefly populations with respect to rainy and dry seasons have been made in Florida, and record rainfall in the Rio Grande Valley of Texas in 1992 apparently contributed to lower whitefly densities relative to other years of lesser rainfall amounts (Riley and Wolfenbarger, 1993).

Information on the potential negative effects of

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rainfall on whitefly populations is important for more than academic reasons alone – the potential to simulate rainfall with overhead sprinkler irrigation opens the possibility of an additional pest management tool. To explore this possibility, we undertook a field study of the impact of sprinkler irrigation on whitefly infestations in crops. Our objectives were to quantify the effect of sprinklers alone or in combination with other treatments on whitefly abundance, and to measure any differences in crop yields according to irrigation treatment.

Materials and methods

Field studies were conducted at the Irrigated Desert Research Station in Brawley, CA during 1992–1993. The effects of sprinkler irrigation on whiteflies in two crops, cotton (*Gossypium hirsutum* L.) and cantaloupe (*Cucumis melo* L.), were studied during the time of year when whitefly populations reach their peak densities in the Imperial Valley. Cantaloupe field trials were completed in both years during the fall melon season (August–November), while a single cotton trial was completed during summer, 1993.

Cantaloupe trials

Cantaloupes (cv. Topmark) were planted both years on alternate 1.0 m beds using a mid-bed trench system that forms trenches 20–30 cm deep in the bed centers (Mayberry and Gonzalez, 1992). Seeds were hand planted 46 cm apart in the trench bottoms prior to covering the beds with 91 cm wide spun-bonded polypropylene row covers (Agribond). A tractor implement was used to stretch the material across the trenches and bury the edges the length of each row so as to exclude dense populations of dispersing whiteflies. Experimental treatments commenced at the time of row cover removal, about four weeks after planting or around the time of first flowering (5–7 leaves).

In 1992, three irrigation treatments in combination with two fungal pathogens and one insecticide were compared by measuring relative abundances of preimaginal whiteflies and yields of cantaloupe fruit. The irrigation treatments consisted of overhead sprinklers applied either daily or biweekly, or furrow irrigation applied on a 10–14 day schedule. A solid-set sprinkler system with a 9.2 × 9.2 m spacing between lateral lines and sprinkler heads was established in each sprinkler plot. Weather Tec 10–60 rainbird heads with 0.031 cm nozzles were used throughout. Timings of sprinkler irrigations were controlled by manually switching power to the electric pump. The goal was to have the same quantities of water applied to each irrigation treatment by varying the duration of irrigations according to treatment. An additional consideration was saturation of the sprinkler-irrigated plots that might inhibit access for leaf samplings. To avoid this, irrigation in the daily sprinkler-irrigated plots generally occurred in the afternoons for a duration of 0.75–1 h each day. Irrigation on Tuesdays and Fridays in the biweekly sprinkler-irrigated plots also occurred primarily in the afternoons, but for a duration of ca. 3–3.5 h.

Insecticide and fungal pathogen treatments were

applied in plots consisting of 8 plant rows by 9.2 m long with 6.1 m separation alleys. Each treatment, including an untreated control, was replicated four times within a randomized complete block design. The fungal pathogen *Paecilomyces fumosoroseus* (Wize) Brown & Smith (PFR) was provided by Dr L. Osborne (University of Florida) and cultured on wheat kernels. Conidia were harvested and suspended to a concentration of ca. 1×10^7 conidia ml⁻¹ in a solution of 1% molasses and 0.05% tween 80. A second fungal pathogen, *Beauveria bassiana* (Balsamo) Vuillemin, was used in the commercial formulation Naturalis® L at the rate of 0.87 l ha⁻¹ of product and tank mixed at the rate of 187 l ha⁻¹. Both fungal pathogens were applied to their respective plots with a backpack sprayer at 207 kPa through a single Teejet 6002 flat-fan nozzle. Two applications per week were made from the time of row cover removal until the eventual destruction of the crop by whiteflies. In the systemic insecticide plots, imidacloprid was applied the day of row cover removal at the rate of 0.42 kg A.I. ha⁻¹. It was diluted at the rate of 187 l ha⁻¹, and 118 ml of the mixture was applied as a soil drench to the crown of each plant.

Densities of immature whiteflies in each treatment plot were estimated weekly by sampling the fifth leaf from the tip of a lateral branch on six randomly selected plants per plot. Whole leaves were detached and returned to the laboratory for counting whiteflies under a microscope. Because of the extreme whitefly densities, only a single 2.5 cm² subsample on the abaxial leaf surface was examined. Leaf subsamples were defined by overlaying a wire grid composed of 2.5 cm² squares onto leaves and randomly selecting a pair of numbers to designate the row and column intersection of the selected square. Eggs and all nymphal stages within the selected square were counted.

Cantaloupe yields were measured by collecting ripe and near-ripe fruits from surviving vines. Individual fruit weights were determined and then percent soluble solids were measured with a refractometer. Only fully netted fruit that had soluble solids ≥8% and weighed ≥720 g were counted for yield. Fruit were categorized into four size classes based on the number of fruit that fit into a standard shipping carton. Size 12 represented the largest fruit at 12 fruits per carton, while size 23 were the smallest at 23 fruits per carton. The following weight ranges were used to estimate fruit size: 23: 720–853 g; 18: 854–1056 g; 15: 1057–1293 g; 12: 1294–1800 g.

A similar experiment was conducted in cantaloupes in 1993, but with fewer treatments. The bi-weekly sprinkler treatment was omitted, leaving daily sprinklers and furrow irrigation as the two irrigation treatments. Also omitted were the fungal pathogen treatments. Rates for imidacloprid were the same as 1992. Plot dimensions were 10 rows by 9.2 m and each treatment was replicated four times. Densities of whiteflies in each plot were estimated from twelve randomly-selected plants per plot. A leaf punch was used to collect a single 2.5 cm² disk from leaves three (young, expanding) and seven (mature, expanded), counted proximally from the tip of a lateral branch. Leaf disks were collected from a basal position on each of the sampled leaves. All eggs and nymphal stages were counted on each leaf disk and expressed as preimaginal

whitefly density per cm². Fruit yields were measured as in the previous year.

Cotton trials

Cotton (cv. Deltapine 5461) was planted in rows on 1 m centers and first irrigated on 11 March. The experiment consisted of two irrigation treatments, daily sprinklers and furrow irrigated, with four of five application treatments identical to the treatments used in the 1992 cantaloupe trial. The fifth treatment consisted of a one time application of aldicarb at the rate of 11.2 kg AI ha⁻¹. Imidacloprid was applied once on 10 June at the rate of 0.56 kg A.I. ha⁻¹ using a 30 ml soil drench per plant. Spray applications of the fungal pathogens began 16 June and continued for four weeks at 1–2 applications per week. Application treatment plots were 12 rows × 15.25 m and replicated four times within each irrigation treatment.

Cotton plants in the sprinkler plot were irrigated beginning at planting time using the same equipment and configuration as for the cantaloupes. Irrigations in the sprinkler and furrow plots were infrequent through the end of May as evapotranspiration demands and whitefly infestations were both low. However, the number of dispersing whiteflies rapidly increased with the advent of spring melon harvest that began in late May, and remained at high levels throughout the summer. Consequently, daily operation of the sprinklers for 1 h duration started 8 June. A weekly schedule for the furrow irrigated cotton began 18 June. Both schedules were maintained through the end of the cotton season, although occasionally days were skipped in the sprinkler plot due to unavailability of the pump. Risers 1.5 m high were installed the first week of July to clear the growing cotton canopy.

Leaf samples were taken weekly from 16 randomly selected plants per subplot. A single leaf disc 2.5 cm² was collected from each of three leaves per plant at mainstem nodes three, four and five counted from the terminal. Leaf discs were punched from the basal portion of the second sector (Naranjo and Flint, 1994) of sampled leaves. Counts of preimaginal whiteflies were made from the abaxial surface of the leaf discs.

Cotton production for each treatment was estimated by sampling 20 m of row in each plot. Five replications of 4 m row lengths were randomly selected and delineated per plot, and then all cotton within these sections was hand picked. The seed cotton was weighed, then ginned for lint weights.

Data analyses

Weekly counts for all experiments were evaluated independently using log-transformed numbers of whitefly eggs and nymphs either individually or combined. Fungal pathogen and insecticide treatments were applied in a randomized complete block design, with replicated blocks as whole plots and irrigation treatments as subplots. The residual error term was used to compute *F* statistics for insecticide/fungal pathogen effects and their interactions with irrigation treatments, whereas the interaction term between block and irrigation treatment was used to compute *F* statistics for irrigation effect. Attrition in all but imidacloprid-

treated cantaloupes following the first two (10, 17 September) or first three weekly counts (22, 29 September, 6 October) of the 1992–93 cantaloupe trials, respectively, left only block and irrigation treatment effects for evaluation. A similar model was used to analyze the eight weekly samplings in the cotton trial and to compare cotton yields. Comparisons among treatment means were made using contrasts when significant ($P < 0.05$) *F* statistics were obtained. All analyses were performed with the computer program JMP (SAS Institute, 1994).

Results

Cantaloupe trials

Intensive whitefly pressure during the late summer-early fall season in the Imperial Valley resulted in high numbers of whitefly adults feeding and ovipositing on young cantaloupe plants. One week following row cover removal in 1992, average whitefly egg counts of ca. 500 per cm² were observed in the furrow irrigated subplots (Figure 1). Significant irrigation effects were apparent from the first two samplings (10 September: $F = 5.6$, $df = 2,6$, $P < 0.05$; 17 September: $F = 8.3$, $df = 2,6$, $P < 0.05$), with significantly fewer eggs in both daily and bi-weekly sprinkler irrigated subplots compared to the furrow irrigated subplot on 10 September, but only in the daily sprinkler subplots compared to furrow subplots on 17 September. Apart from the significantly lower number of eggs in the imidacloprid treated plots (10 September: $F = 161$, $df = 3,27$, $P < 0.0001$; 17 September: $F = 38$, $df = 3,27$, $P < 0.0001$) no other statistical differences

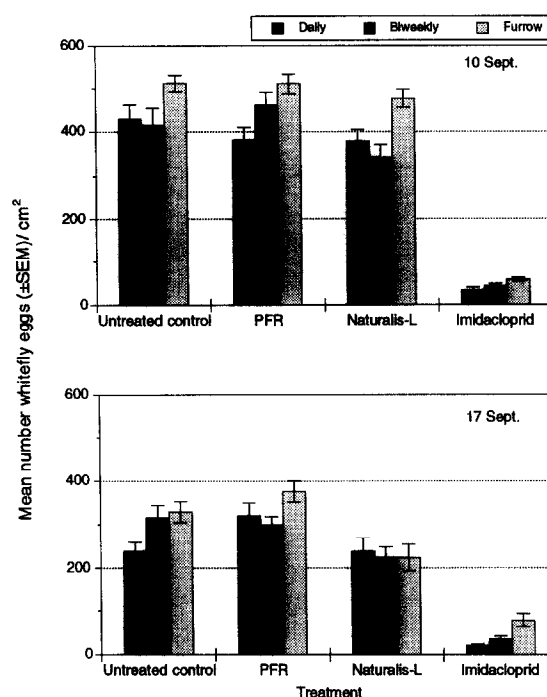


Figure 1. Comparison of whitefly egg densities on cantaloupe leaf disks sampled from insecticide/fungal pathogen treated or untreated control plots under three different irrigation regimes, daily sprinkler, biweekly sprinkler, or furrow irrigated on the first two sampling dates, 1992

were observed among the untreated control, PFR, or Naturalis-L treatments. No significant interactions between fungal pathogen/insecticide treatments with irrigation treatments were observed for any sampling date. By the third week following row cover removal, collapsing cantaloupe vines in all non-imidacloprid treated plots precluded further evaluations.

Differences in densities of preimaginal whiteflies among irrigation treatments were often significant in the imidacloprid treated plots (Figure 2). Daily sprinkler irrigated cantaloupes had significantly lower densities of eggs than the furrow irrigated cantaloupes in three of four comparisons, whereas the biweekly sprinkler-irrigated melons differed significantly (17 September: $F = 13$, $df = 2,6$, $P < 0.01$; 25 September: $F = 25$, $df = 2,6$, $P < 0.01$) from the furrow irrigated melons in two of four comparisons (Figure 2a). Consistently fewer eggs were observed in the daily sprinkler subplots compared to the biweekly sprinkler subplots, but only one of six comparisons was significantly different (23 October: $F = 15$, $df = 1,6$, $P < 0.05$). Similarly, nymphal counts were consistently lower in the daily sprinkler subplots (Figure 2b), with only two of six comparisons significantly different (2 October: $F = 27$, $df = 2,6$, $P < 0.01$; 23 October: $F = 20$, $df = 1,6$, $P < 0.05$). Only melon plants under daily or biweekly sprinkler irrigation in the imidacloprid treated plots survived to produce mature fruit, with the furrow irrigated melons collapsing after 2 October.

As with the previous year, imidacloprid treated cantaloupes in 1993 had much lower densities of preimaginal whiteflies compared with the untreated control (Figure 3). Similarly, numbers of whiteflies from sprinkler irrigated plots were consistently lower

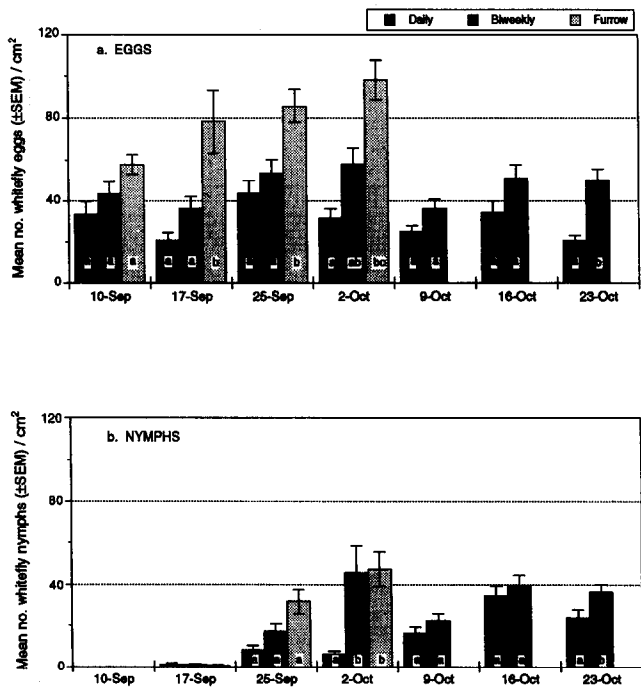


Figure 2. Densities of whitefly (a) eggs and (b) nymphs in imidacloprid treated cantaloupes subjected to the same three irrigation treatments as Figure 1. Different letters within each bar denote significant treatment differences ($P < 0.05$) for the respective sampling dates, 1992

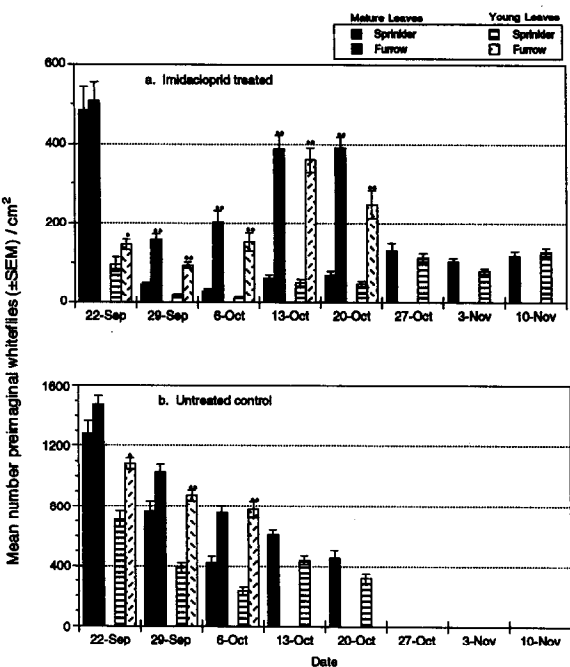


Figure 3. Comparison of preimaginal whitefly densities on young or mature cantaloupe leaves in untreated control plots or imidacloprid treated plots under furrow or daily sprinkler irrigation, 1993. Asterisks above bars indicate significant differences (*, $P < 0.05$; **, $P < 0.01$) between furrow and sprinkler irrigation treatment means independently for young and mature leaves

than in furrow irrigated plots in both imidacloprid treated and untreated control plots. Whitefly densities on young leaves were lower than on mature leaves, but the relative difference between sprinkler and furrow irrigated treatments was similar for both leaf age classes (Figure 3). This was corroborated by the positive correlation between densities of preimaginal whiteflies on young and mature leaves ($r = 0.83$, $n = 972$), $P < 0.001$).

Cantaloupe fruit yields were marginal in both 1992 and 1993 due to cumulative damage from season-long attack by whiteflies. Full-netted, mature trees tended to be small-sized with a low soluble solids content (Table 1). Nearly three times more fruit were produced in the daily sprinkler plots in 1992 compared to the same year's biweekly sprinkler plots or the daily sprinkler plots in 1993.

Cotton trial

Although mass movement of whitefly adults into the 1993 cotton trial (coinciding with commercial cantaloupe harvest) began in mid-June, buildup of the preimaginal population tended to be more gradual. Significant differences in whitefly densities between sprinkler and furrow irrigated cotton among all treatments occurred with the first sampling date (16 June: $F = 9.6$, $df = 1,30$, $P < 0.01$). This pattern was maintained for each subsequent sampling date, with the margin of difference between sprinkler and furrow irrigated densities of whiteflies increasing through the summer up to the last sampling date (Figure 4). A surge in whitefly abundance in the sprinkler irrigated plots

Table 1. Mean (\pm SEM) quantities and percent soluble solids of cantaloupe fruit harvested from imidacloprid-treated plots under sprinkler irrigation applied on a daily or biweekly schedule during 1992–93 trials. All fruit represented in this table met minimum standards (weight ≥ 720 g, soluble solids $\geq 8.0\%$) for market quality. Furrow irrigated cantaloupe plants did not survive whitefly attack to produce fruit

| Fruit* size | 1992 | | | | 1993 | |
|-------------|-----------------|----------------|----------------|----------------|----------------|-------------------|
| | Daily | | Biweekly | | Daily | |
| | Quantity | Soluble solids | Quantity | Soluble solids | Quantity | Soluble solids |
| 12 | 2.8 \pm 1.1 | 10.0 \pm 0.3 | 0.5 \pm 0.3 | 9.5 \pm 0.5 | 0.5 \pm 0.3 | 10.0 [†] |
| 15 | 12.8 \pm 3.2 | 9.9 \pm 0.1 | 3.5 \pm 1.6 | 9.6 \pm 0.4 | 1.3 \pm 0.3 | 10.8 \pm 0.9 |
| 18 | 25.0 \pm 5.1 | 9.2 \pm 0.1 | 8.0 \pm 2.4 | 9.1 \pm 0.1 | 11.8 \pm 1.6 | 9.7 \pm 0.2 |
| 23 | 16.0 \pm 1.8 | 8.7 \pm 0.1 | 8.5 \pm 1.9 | 8.9 \pm 0.2 | 9.0 \pm 1.6 | 9.4 \pm 0.2 |
| Combined | 56.5 \pm 10.4 | 9.2 \pm 0.1 | 20.5 \pm 5.3 | 9.1 \pm 0.1 | 22.5 \pm 2.8 | 9.7 \pm 0.1 |

*Based on number of fruit that fit into standard size carton, with 12 fruit/carton representing the largest size and 23 fruit/carton the smallest
[†]One observation only

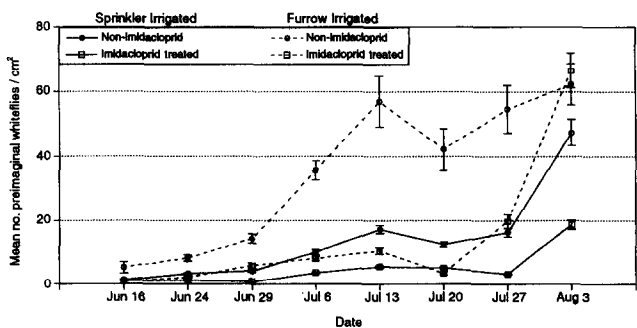


Figure 4. Comparison of preimaginal whitefly densities in sprinkler or furrow irrigated cotton treated with imidacloprid or other (non-imidacloprid) treatments, 1993

was recorded on the last sampling date, but they were still significantly less dense than furrow irrigated plots (3 August: $F = 6.2$, $df = 1,30$, $P = 0.05$). Numbers of whiteflies were consistently lowest in the imidacloprid treated plots, differing significantly from all other treatments on all eight sampling dates experiment wide. However, evidence of diminishing protection by imidacloprid was apparent by the last date as there was no difference in furrow irrigated cotton between the imidacloprid treatment and the other treatments (Figure 4). Treatments with the fungal pathogens or with aldicarb had no significant effect on whitefly abundance relative to the untreated control, and therefore counts from these treatments were grouped into a non-imidacloprid category for comparison (Figure 4). There were no significant interactions for any sampling date between irrigation effects and insecticide or fungal pathogen effects.

Cotton yields were significantly higher in the furrow irrigated than the sprinkler irrigated cotton plots despite being more heavily infested with whiteflies (Table 2). Cotton growth in the sprinkler irrigated plots appeared to be more vegetative than the furrow irrigated plots, an outcome identified previously by Plaut, Ben-Hur and Meiri, (1992). Cotton yield was significantly higher $F = 5.2$, $df = 1,30$, $P = 0.05$) in the imidacloprid treated plots than all other treatments across both irrigation treatments.

Table 2. Mean (\pm SEM) cotton lint yields (kg/ha) in furrow or sprinkler irrigated cotton in 1993 under insecticide or fungal pathogen treatments or untreated control

| Treatment | Irrigation treatment | |
|-------------------|---------------------------|---------------|
| | Sprinkler | Furrow |
| Imidacloprid | 157a [†] \pm 7 | 190a \pm 10 |
| Aldicarb | 122b \pm 6 | 164a \pm 14 |
| Naturalis-L | 116b \pm 5 | 136a \pm 9 |
| PFR* | 123b \pm 6 | 119a \pm 7 |
| Untreated control | 100b \pm 4 | 117a \pm 9 |

**Paecilomyces fumosoroseus*
[†]Means within each column followed by the same letter are not statistically different HSD, $P = 0.05$

Discussion

Significant reductions in whitefly eggs and nymphs in sprinkler irrigated crops compared with furrow irrigated cantaloupe and cotton crops was a consistent finding in all three trials. Moreover, the beneficial effect of sprinklers was apparent, irrespective of insecticide, fungal pathogen or no treatment. The long-lasting, systemic activity of imidacloprid greatly reduced the numbers of colonizing whiteflies, and thus provided a better opportunity to observe the suppressive effect of sprinkler irrigation, especially in the highly whitefly-susceptible cantaloupes. Only through the joint action of imidacloprid treatment and sprinkler irrigation was any mature fruit harvested, albeit low quantity and quality. The fruit yields from both cantaloupe trials corroborated the relative densities of whiteflies from the respective irrigation treatments, with fruit harvested only from the sprinkler plots both years, and a higher quantity harvested from the daily compared with biweekly sprinkler plots in 1992. Variable conditions may account for fruit yield differences between years, whereas yield differences between daily and biweekly sprinkler treatments in 1992 appear directly related to differences in densities of whiteflies.

The causal nature of whitefly suppression by sprinklers was not elucidated in this study, but appears to involve a disruptive effect on adult whiteflies. This can

be inferred to some extent by fewer whiteflies (and higher fruit yields) in the daily sprinkler plots compared with the biweekly sprinkler plots in 1992. Both treatments received about the same total irrigation, but the daily sprinklers were applied about three times more frequently, but for a shorter duration. Adult whiteflies infesting the sprinkler plots were often observed to take brief flight as water droplets impacted leaves.

In general, whiteflies have a well developed alarm response to mechanical disturbance of their leaf substrate or to physical contact. Either type of stimulus occurs with sprinklers, but likely would primarily involve mechanical disturbances to leaves because the underleaf habits of whiteflies help avoid direct contact with falling water droplets. Any disturbance sufficient to cause whitefly flight would mean less time for feeding, mating and/or oviposition behaviors, and would be compounded by the time spent to re-engage in any of these behaviors. The disruptive effect could be maximized if the timing of the sprinkler application coincided with a known behavioral/physiological periodicity such as was demonstrated for adult emergence from the pupal stage (Byrne and von Bretzel, 1987).

A disappointing outcome of this study was the failure of the fungal pathogens to reduce whitefly infestations, especially in combination with sprinkler irrigation. The environment often limits the effectiveness of fungal pathogens due to high temperatures and/or low humidities. The greater tolerance of cotton under heavy whitefly pressure provided a longer period to observe the potential benefit of fungal pathogens compared to the 1992 cantaloupe trial. Although isolated cases of infected whitefly nymphs were observed, apparently the conditions were too harsh to allow an epizootic that would have been necessary to impact the heavy whitefly infestations. Moreover, the fungal pathogens were tested under the most extraordinary conditions, with constant heavy immigration pressure during all three trials that conceivably overwhelmed any biological control by the pathogens.

Statements connecting the adverse effects of rainfall on insect populations are not uncommon, as with the report of the pestiferous occurrence of cassava mealybug only during the dry season in the African tropics (Van Dijken *et al.*, 1991) or the reports of greater insect abundances occurring during the dry season in the Central American tropics (Wolda, 1982; Janzen, 1983). Few other studies have examined the potential impact of sprinkler irrigation on insect populations. Notable exceptions, however, were two studies in Hawaii that demonstrated the controlling effect of sprinkler irrigation on diamondback moth infestations of watercress by severely reducing egg deposition (Tabashnik and Mau, 1986; Nakahara *et al.*, 1985).

The findings in this study suggests further research into sprinkler irrigation as a whitefly control measure may be warranted. A potential limitation to the wider use of sprinklers is the higher costs associated with sprinkler irrigation compared to furrow irrigation. However, higher irrigation costs might be partially offset if reduced infestations resulted in less insecticide use. Further reduction in pest control expenditures could be possible if chemigation practices were utilized; thereby lowering costs associated with ground or air

applications. More efficient delivery of water to plants occurs with sprinkler irrigation compared to furrow irrigation, and better yields are realized in some crops like potatoes (Trout, Kincaid and Westermann, 1994). Thus, lower water costs and increased yields also would mitigate higher irrigation costs from using sprinklers. Finally, similar to the beneficial effects of timely rainfall (Henneberry *et al.*, 1995), sprinkler irrigation in cotton could help to eliminate price discounts imposed by cotton ginners due to honeydew contaminated lint associated with whitefly infestations.

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